A STUDY OF OPTIMUM ROAD ROUTE DECISION USING MULTI EVALUATION FACTORS

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ABSTRACT

A study of quantification method of evaluation factors for optimum road route is represented. First, quantitative evaluation criteria are derived based on expert survey. Quantitative evaluation criteria are divided into safety evaluation, road geometry, and environmental criteria. Here, safety evaluation is performed through the traffic accident analysis and environment factors are divided into natural environment and circumstance. Also, road geometry contains horizontal alignment, vertical alignment, and operation of alignment. And rational weights of each quantitative evaluation criteria inherent in each level and step for optimal road route design procedure are decided using ANP (Analytic Network Process) method. Analytic Network Process (ANP) which deals with the dependency and feedback is used for handling all kinds of interactions and make accurate predictions, and, even further, to make better decisions.

For applicability to in-field road design, a feasibility study is carried out after performing safety evaluation, road geometry evaluation, and environmental evaluation. It is concluded that the proposed optimal road route design method will provide a new solution to decide road planning and expected to contribute the development of user-friendly road design technology according to social condition change.

Keywords: Optimum road route, Quantitative Evaluation, Decision Making, Multi Evaluation

1. INTRODUCTION

The configuration of the road is an important factor to be considered in making a decision for the road planning. Nevertheless, current road planning criterion has no such clarified and objective judging standard for figuring the configuration of the road out. In this study, a decision model for optimal road route selection is proposed. First, quantitative evaluation criteria are derived based on expert survey. And rational weights of each quantitative evaluation criteria inherent in each level and step for optimal road route design procedure are decided using ANP (Analytic Network Process) method.

During the last decade, the AHP has become one of the most widely used methods for achieving practical solutions to numerous ranking problems in different areas of human needs and interests. However, AHP method which has a limit for solving the decision problems has the interaction and dependence of higher level elements on lower level elements. Therefore, Analytic Network Process (ANP) which deals with the dependency and feedback is used for handling all kinds of interactions and make accurate predictions, and, even further, to make better decisions [9].

Quantitative evaluation criteria are divided into safety evaluation, road geometry, and environment. Here, environmental factors are divided into natural environment and circumstance. And road geometry contains horizontal alignment, vertical alignment, and operation of alignment.

For applicability to in-field road design, safety evaluation based on traffic accidents statistics and intelligent road design program are used for feasibility study.

2. EVALUATION FACTORS FOR ROAD ROUTE SELECTION

In order to establish a model which can select the reasonable road route by taking into consideration multi evaluation factors, this study comes up with detailed evaluation factors for traffic safety, road geometry, environment and economic factor. Safety factor are divided by performing traffic accident analysis and evaluating the degrees of safety based on accident rates. And also, the road geometry factors are broken down into 15 factors through discussions with road design experts. The environmental factor is classified into 5 second-level factors and the economic factors are applied after the estimated construction cost is approximately calculated based on the unit meter.

Safety evaluation factors with respect to road alignment

The impact of horizontal alignment design based on traffic accidents is analyzed in relation to the road route design characteristics. For this purpose, general roads are divided into some clearly defined groups considering their characteristics related to connectivity between prior and posterior sections, direction of horizontal curves, and length of straight sections. Then, the roads are analyzed to identify the impact of design characteristics of road sections on traffic accidents. And the status data related to horizontal alignment design factor and characteristics of traffic accidents along the domestic expressway are collected and analyzed statistically.

First, the safety evaluation factors are selected by integrating the results of previous related studies which can clarify the relationship between alignment and traffic accidents. Second, the accident rates in line with evaluation factors are examined by making connection between the road alignment data and the data of generated traffic accidents which are surveyed and collected along the domestic expressways. And at this stage, this study analyzes how to deal with short-length straight section and long-length straight section differently and which variables, respectively in each case, have higher impact on traffic accidents. In handling such cases, this study differentiates between the curved sections that come up after straight sections and the curve sections that follow previous curve sections. Third, the degree of safety of road route based on the accident rate is evaluated. Road alignment related data are collected from the selected 13 expressways (total length of 2,851km), and the accidents data are also collected through the selected expressways. In order to analyze the relationship between road alignment and accident rate, the statistical yearbooks on traffic volume and statistics on traffic accidents on expressways are collected. The data used in this study basically covers whole expressways. However, 88 Olympic Highway are excluded because of its regional and geometric characteristics. Also, expressways within the metropolitan area, such as Second Seoul-Incheon Expressway, Seoul Ring Expressway, and Incheon International Airport Expressway are also excluded because those ways are expected to be different from other normal expressways in terms of traffic volume and driving speed.

Through the screening process, the safety evaluation factors were finalized. They includes not only the horizontal alignment factor which consists of length of straight section, length of curve section and scale of curve radius, but also the vertical alignment factor for which the vertical slope is selected as a factor also. The aspect of alignment operation was excluded because there were difficulties in grading for quantification of analysis results of traffic accidents

Table 1 Safety evaluation factors with respect to road alignment

Classification	Evaluation factors
Horizontal alignment	Length of straight section, length of curve section, scale of curve radius,
Vertical alignment	Vertical slope
Aspect of alignment operation	-

Road geometry evaluation factors

In order to perform a study on selecting the optimal road route, the road geometry evaluation factors which would have impact on road route selection are established and quantified. First of all, the road geometry evaluation factors are divided into 3 second level factors, such as horizontal alignment, vertical alignment and alignment operation, and then they are divided into 27 third level factors based on [1][2][3][4][6]. Then, 27 subdivided factors were reviewed thoroughly. In order to secure the correctness and reliability of the questionnaire, the pilot survey targeted for 15 experts, including

people with doctor's degree, was conducted. After the questionnaire was revised and supplemented, it was finalized and then the expert survey was conducted. The expert survey was targeted for those experts in academy (at least master's degree), specialized research institutes (Korea Expressway & Transportation Research Institute), public employees, and experts working for related engineering companies. Total 100 questionnaires were distributed and responded 75%. Frequency analysis was performed on the responded questionnaires from the respondents. After calculating the consistency ratio for each respondent of the responded 75 questionnaires, respondents whose consistency ratio was lower than 0.1 were excluded from the sample of weight calculation. It could be understand that the factors with highest values need to be considered as priorities in the evaluation of road route, as summarized in Table 2.

Table 2 Alignment design evaluation factors

Evaluation factors			Regulation	Recommendation	Statistic
Alignment	Horizontal alignment	Horizontal curve radius	○	○	○
		Length limit of straight section		○	○
		Distance between IPs			○
		Horizontal curve radius ratio		○	○
		Minimum curve length	○		
		Degree of curvature			○
	Vertical alignment	Change rate of vertical curve	○	○	○
		Vertical curve length	○		○
		Maximum vertical slope	○		○
		Tunnel vertical curve		○	
		Response with respect to VIP installation		○	
		Vertical concavity		○	
		Minimum height from the top of a tunnel to the ground			
	Alignment operation	Vertical flection test 1		○	
		Vertical flection test 2		○	

Environmental evaluation factors

For selecting the environmental evaluation factors, this study tried to apply 6 factors for environmental evaluation based on [8]. However, the amusement/scenery factor was excluded because difficulties met in the quantification due to the higher level of subjectivity. Moreover the possibility is existed in overlapping with other 5 factors. Thus, 5 factors are selected in this study can be summarized as follows;

- Topography&geology : Evaluation factor related not only to minimization of damage to topography due to ground cutting and banking filling for road construction, but also to conservation of topography and geology which deserve preservation.
- Fauna&flora : Evaluation factor related not only to minimization of damage to areas which deserve being protected and preserved as habitats for animals and plants, but also to protection of animals and plants and maintenance of their diversity.
- Water quality : Evaluation factor related to protection not only of those areas which are considered as important in terms of water quality, but also of the areas which can be significantly influenced by road construction.
- Air quality : Evaluation factor related to protection of the areas which are expected to go through significant change due to road construction.
- Noise&vibration : Evaluation factor related to protection of the areas which are expected to be susceptible to the impact from road construction.

3. QUANTIFICATION OF THE OPTIMAL ROAD ROUTE EVALUATION FACTORS

This study proposes the method which not only applies the quantitative weight to each of the optimal road route evaluation factors, but also quantifies the evaluation factors through accident rate analysis, expert survey, ANP analysis and hierarchy structure.

Quantification of safety evaluation factors

Through the analysis of accidents data as shown in Table 3, the accident rates for straight sections are comparatively high in case of shorter than 400m or longer than 3,500m. Especially the accident rate for the sections which are shorter than 100m is extremely high. Considering that it is still highly possible for accidents to take place at the curve sections that follow the short-length straight sections, the actual danger could be severely higher as long as the short-length straight sections exist.

Table 3 Accident rates depending on the length of straight sections

Range of L (m)	Accident rate (0.1billion/km)	Range of L (m)	Accident rate (0.1billion/km)	Range of L (m)	Accident rate (0.1billion/km)	Range of L (m)	Accident rate (0.1billion/km)
~100	5.1	~600	2.9	~1300	2.8	~2000	2.7
~200	3.8	~700	2.6	~1400	2.4	~2500	3.1
~300	4.4	:	:	:	:	~3000	2.0
~400	3					~3500	2.3
~500	2.9	~1200	2.7	~1900	2.1	~4000	4.7
						>=4000	3.6

As shown in Table 4, the accident rates for most of the curve sections are similar, except for the curve sections which are shorter than 500m. Also, as shown in Table 5, the accident rates for most of the sections are similar, while the accident rate for the sections whose horizontal curve radius is shorter than 600m is high.

Table 4 Accident rates depending on the length of curve sections

Range of L (m)	Accident rate (0.1billion/km)	Range of L (m)	Accident rate (0.1billion/km)	Range of L (m)	Accident rate (0.1billion/km)	Range of L (m)	Accident rate (0.1billion/km)
~100	0	~600	3.2	~1300	2.2	~1900	2.1
~200	5.9	~700	3.7	~1400	2.8	~2000	2
~300	3.1	:	:	:	:	:	:
~400	3.9						
~500	4.8	~1200	3	~1800	2.8	~4000	3.7

Table 5 Accident rates depending on the radius of curve sections

Range of L (m)	Accident rate (0.1billion/km)	Range of L (m)	Accident rate (0.1billion/km)	Range of L (m)	Accident rate (0.1billion/km)	Range of L (m)	Accident rate (0.1billion/km)
~200	2.2	~700	4.1	~1400	4.4	~2000	2.7
~300	0	~800	3.7	~1500	2.7	~2500	2.6
~400	10.9	:	:	:	:	:	:
~500	9.2						
~600	5.7	~1300	2.8	~1900	1.7	4000~	2.6

Based on the results above, the safety evaluation of horizontal alignment applies 100 points, as shown in the Table 6, for the sections whose accident rate is lower than 2.0 (per 0.1 billion/km) with respect to curve length, straight length, and curve section radius. And 80 points is applied for the section whose accident rate is lower than 3.0 and 50 points is applied for the section whose accident

rate is higher than 4.0 based on the subjective judgment that the accident rate for those sections is relatively high.

Table 6 Points for safety evaluation of horizontal alignment

Accident rate (0.1billion/km)	Points for safety	Remarks
~ 2.0	100	
2.0 ~ 3.0	80	
3.0 ~ 4.0	60	
4.0 ~	40	

According to the accident rates along the whole range of vertical slopes, the accident rate for the downward inclined sections whose slope is lower than -4% is high. Strangely, as shown in Table 7, the section whose slope is around 0% shows the tendency of high accident rates. Accordingly, the safety evaluation of vertical alignment applies 50 points for the sections whose slope is lower than -4%, while applying 100 points not only for the sections whose downward inclination is higher than -4% but also for the upward inclined sections, as shown in Table 8. These points applied based on the quantitative safety evaluation can be improved according to, if performed, more detailed analysis of traffic accidents and opinions from experts.

Table 7 Accident rates depending on vertical slope

Range of S (%)	Accident rate (0.1billion/km)	Range of S (%)	Accident rate (0.1billion/km)	Range of S (%)	Accident rate (0.1billion/km)	Range of S (%)	Accident rate (0.1billion/km)
~ -6	25.1	~ -2	12.8	~ 2	10.4	~ 6	8.1
~ -5	11.5	~ -1	13.3	~ 3	9.1	6 ~	4
~ -4	18	~ 0	13.9	~ 4	7.7		
~ -3	11.1	~ 1	13	~ 5	10.6		

Table 8 Points for safety evaluation of vertical alignment

Vertical slope (%)	Points for safety evaluation	Remarks
≥ - 4.0	100	
< - 4.0	50	

Quantification of road geometry evaluation factors

For determining the quantification of the geometry of road route, various standards and previous studies [4] [5] [6] [7] are used. In detail, the condition which must be followed are termed as "regulation", and the condition which need to be followed, if possible, are termed as "recommendation", and the condition based on road design alignment DB analysis is termed as "statistics". Whether each evaluation factor is determined as "regulation", "recommendation" or "statistics" depends on the characteristics of each factor and the related evidence.

For assigning the points with respect to "regulation", only OK or NG is applied. Considering that the "regulation" must be followed, any road alignment which can not satisfy the regulation is to be excluded from the evaluation regardless of the "recommendation" or "statistics" being satisfied. The "regulation" has total 5 evaluation factors, such as curve radius, minimum curve length, change rate of vertical curve, vertical curve length, and maximum vertical slope. Whether those factors can satisfy the conditions or not are to be determined. The "recommendation" has total 9 evaluation factors. For assigning the points with respect to the "regulation", the range of 50~100 points is selected through entering various values by utilizing the design standards and specifications. For example, in case of horizontal curve radius, 100 points is assigned if satisfied, and 50 points is assigned if not satisfied by taking into consideration the minimum curve radius of the criteria for the actual design as shown in Table 9. Other road geometry factors are determined similarly.

Table 9 Recommended horizontal curve radius

Classification	Stopping sight distance S(m)	Distance to road center Y(m)	Curve radius R(m)		Points
			Calculated	Applied	

Design speed	80km/h	110	3.3	459	460	Satisfied:100 Not satisfied: 50
	90 km/h	130	3.3	641	650	
	100 km/h	155	3.3	911	920	

The "statistics" has total 8 evaluation factors to be assigned with points. Assuming that the most previously designed alignment can be the optimal alignment, this study utilizes alignment DB system, which was made based on the design data of the expressways, such as JeonJu~Gwangyang Expressway, Mokpo~Gwangyang Expressway, Jumunjin~Sokcho Expressway, Eumseong~Chungju Expressway. And sets 100 points for the statistic value with highest frequency according to the location of DB and then assign points according to the distribution ratio.

In order to obtain the weight of geometry factors, ANP analysis [6] for the selection of weights for road geometry is performed. For this the mutual subordination and correlation has been investigated through the expert survey. The final correlation is determined, as shown in Fig. 1, through feedback process.

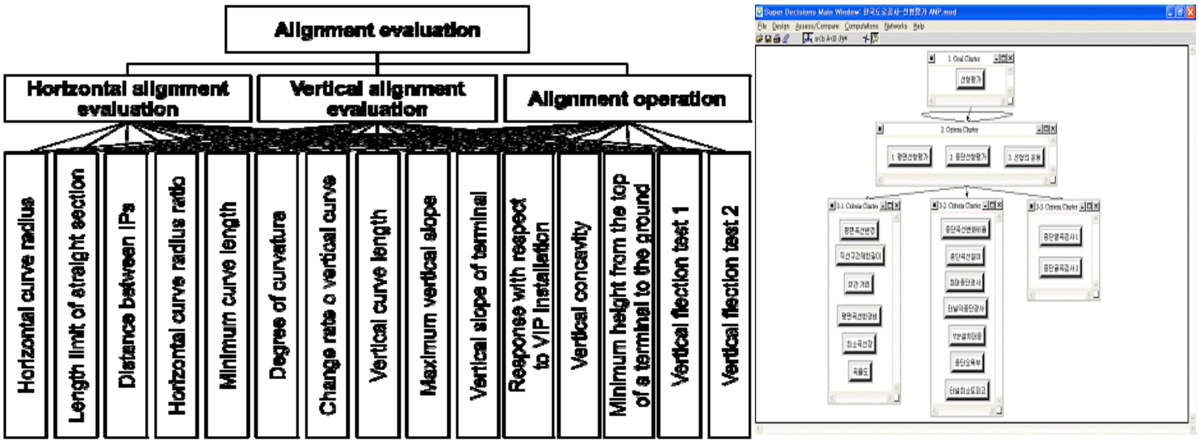

Fig. 1 ANP network structure and analysis screen

The calculation for supermatrix which includes network relationship requires highly complicated and difficult mathematical calculating process. In order to perform the complex calculation, the correlation data were inputted into Super Decisions [6], a commercial program, and subsequently the related results were acquired. In the first level classification, the horizontal alignment evaluation is determined as the highest priority as shown in Table 10. Among the factors for horizontal alignment evaluation, the horizontal curve radius shows the highest points in priority. Of the factors for the vertical horizontal evaluation, the maximum vertical slope is analyzed as the highest priority.

Table 10 Results of ANP priority analysis

Evaluation factor			Weight	Factor priority
First level	Horizontal alignment evaluation		0.446	1
	Vertical alignment evaluation		0.378	2
	Alignment operation		0.174	3
Second level	Horizontal alignment evaluation	Horizontal curve radius	0.440	1
		Length limit of straight section	0.045	5
		Distance between IPs	0.042	6
		Horizontal curve radius ratio	0.124	3
		Minimum curve length	0.107	4
		Degree of curvature	0.240	2
	Vertical alignment evaluation	Change rate of vertical curve	0.221	2
		Vertical curve length	0.126	3
		Maximum vertical slope	0.486	1

		Vertical slope of tunnel	0.085	4
		Response with respect to VIP installation	0.052	5
		Vertical concavity	0.017	6
		Minimum height from the top of a terminal to the ground	0.003	7
	Alignment operation	Vertical flection test 1	0.75	1
		Vertical flection test 2	0.25	2

During the whole process for establishing geometry factors and for calculating weights of each factor, in order to acquire the final points for the quantitative evaluation factors for geometry, the points for each evaluation factor are calculated, and then the weight for each factor is applied based on the expert opinions collected from expert survey, as shown in Table 11.

Table 11 Calculation of evaluation points (Example)

	Recommendation	Statistics	Remarks
Evaluation results	80	90	
Significance	50	50	Sum=100
Weighted points	4000	4500	Evaluation results x Significance
Final points	85		Weighted points/100

Quantification of environmental evaluation factors

This study proposes the methods for quantification of each evaluation factor for environment. In terms of the evaluation indices, the related legal restrictions were reviewed and adopted as the legal standards, and the environmental criteria compatible with the purpose of this study were selected and reviewed based on examination of related documents [1] [5].

In order to assign weights by taking into consideration the selected environmental evaluation factors and indices, environments are divided into natural environment and circumstance. And the selected third level evaluation factors are subdivided into 5 detailed criteria. The indices are divided into 3 different grades and applied with weights through AHP analysis performed in line with the hierarchy structure.

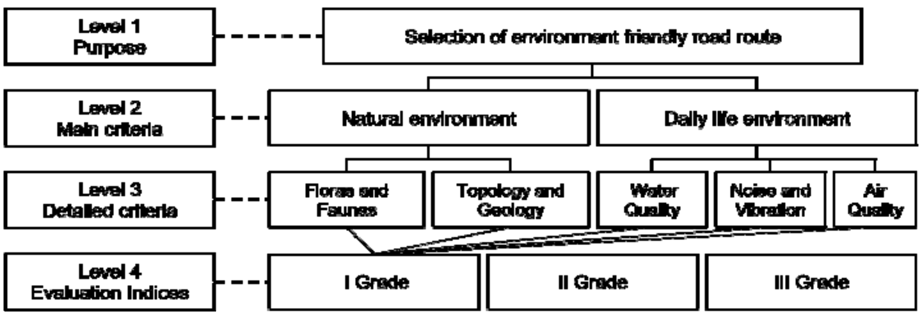

Fig. 2 Levels of environmental evaluation factors and indices

Table 12 Criteria for grading of evaluation indices

Grade of evaluation indices	Criteria for grade
I	i) Deserve exclusive preservation ii) Much expected to suffer wide scope degradation and damage iii) Actually without measures for attenuating impact

II	ⅰ) Highly deserve non-exclusively preservation due to possible impact on the 1st grade value. ⅱ) Expected to suffer wide scope degradation and damage ⅲ) Measures are available for minimizing impact even though it is difficult to be rehabilitated.
III	ⅰ) Deserve preservation but without high value for non-exclusive preservation. ⅱ) Possible to suffer degradation and damage, but without much impact on current status ⅲ) Measures are available for attenuating impact in a way that is similar to the level of rehabilitation.

The weights of 5 environmental evaluation factors previously calculated in [7] are reflected, which are topography/geology, floras/faunas, water quality, air quality, and noise/vibration. For example, in case of topography/geology, those evaluation indices, such as preservation-deserving topography/geology, degree of slope, altitude, risk of landslide, are classified into 3 different grade groups and applied with weights. The same methodology is also applied for calculating weights for other evaluation factors.

Based on the weights for each hierarchy, the final weights for evaluation indices of each grade are consolidated as below. The comparative significance of floras and faunas are highly rated compared with other factors in a way that the weights escalate in the order of Floras and Faunas 1st Grade > Noise and Vibration 1st Grade > Topography and Geology 1st Grade, as shown in Table 13.

Table 13 Final weights of environmental factors

Classification		Weight for each grade		
		Grade I	Grade II	Grade III
Natural environment	Topography/Geology	0.128	0.047	0.018
	Floras/Faunas	0.309	0.108	0.037
circumstance	Air quality	0.045	0.019	0.008
	Noise /Vibration	0.142	0.044	0.017
	Water Quality	0.052	0.019	0.007

4. DECISION MAKING OF OPTIMAL ROAD ROUTE

The intelligent program for optimal road design, already developed in previous study [1], is a kind of computerized road alignment design program with a concept which can produce optimal alignment by analyzing numerous factors. This program is modified in this study. Actually, some modification to the design evaluation factors and weights is performed for determining the design score. ANP analysis method is newly included for calculating weights of geometry factors. Moreover, safety evaluation process and module is developed in this study. The weights of environment factors are adjusted by carrying out the expert survey and questionnaire.

The intelligent program for optimal road design is run by the principle in which, once the start and end points are given, in order to find a road alignment which can satisfy the natural and social requirements and be the most safe and economical, the spatial analysis system, genetic algorithm, and expert system go through mutual convergence, grafting, and integration, and, subsequently, numerous alignments are generated and the alignments go through expert system applied evaluation process that utilizes genetic GA (Genetic Algorithm), finally producing an optimal alignment.

Program flowchart for selecting the optimal road route

The modified program for optimal road design mainly consists of 3 functions, alignment generation, alignment evaluation and alignment optimization. The alignment evaluation function carries out calculation respectively for environment score, design score and construction cost for the purpose of evaluating the arbitrarily generated alignments. Fig 1 shows how the program flows for the work of optimal road selection. The functions for each stage are as shown in Table 14.

Fig. 3 Program flowchart for selecting the optimal road route

Table 14 Functions for each stage of the optimal road route selection program

Classification	Functions for each stage
1stage Numeric mapping analysis	Extract evaluation factors and perform buffering by analyzing local altitudes (TIN) and grids based on a numeric map.
2nd stage Entering by designer	Enter the alignment related data, such as start and end points and key CPs and adjust the weights and resistance for each evaluation factor for the roads within the areas targeted for search for optimal road routes.
3rd stage Search for optimal alignment	Produce the initial alignment candidates by utilizing genetic algorithm, and let the candidates go through the repetitive process of selection, cross-breeding and mutation to be narrowed down to the optimal alignment.
4th stage Repetition of each alternative	Extract several alternative road routes by going through the 2nd and 3rd stages repetitively while adjusting the values inputted by designers.
5th stage Extract final optimal design plan	Responsible person for road design confirms the final optimal design plan among several alternatives produced

Alignment evaluation by the optimal road route selection program

As shown in Fig. 4, the alignment evaluation is performed in a process that horizontal alignment is generated first, then vertical alignment for the generated horizontal alignment is automatically configured, and, simultaneously, construction cost for the structure (Bridges or tunnels) is calculated. And also, earthwork cost is calculated through automatic configuration of the vertical alignment, and, lastly, after the environment evaluation scoring is performed on the horizontal/vertical alignments, then the final alignment evaluation score is produced by considering the scores for construction cost as well as environment. At last step, safety evaluation scoring is performed of each alternative road route.

5. FEASIBILITY STUDY OF THE EVALUATION FACTORS

For applicability to in-field road design, the 14.8km section of total length of 90km of 00-00 expressway whose basic design was completed recently, and subsequently produces the optimal road route for the expressway is selected. The start and end points and GIS data/Tin of the candidate alignments are set, and the specifications and data of the candidate alignments, such as horizontal alignment option, vertical alignment option, cross-section alignment option and evaluation option are entered to produce the candidate alignments. The alignments are generated as shown in Fig. 5. The candidate alignment 1 is a road route which has taken into consideration economic feasibility,

environmental feasibility and design score while without considering the safety evaluation module. The candidate alignment 2 is the optimal road route which reflects even the safety evaluation.

Fig. 4 Alignment evaluation process

Fig. 5 Comparison of design route and alternatives

Comparison of estimated construction cost

The estimated construction cost is calculated. Approximately, construction cost of structures is calculated in a way that the unit price per unit quantity is applied without taking into consideration the types of tunnels and bridges. The earthwork cost is calculated in a way that the earthwork volume is totally based on the volume of earth and sand because there is no data available for the dark lines of the alternatives.

The next data is the comparison results of the estimated construction costs for a road alignment running from 00 ~00 (STA.46+000~STA.62+500) targeted for the comparison. As shown in Table 15, through comparing the estimated construction costs by applying earthwork cost, bridge cost and tunnel cost for each alternative, comparison results are represented.

Table 15 Comparison of estimated construction cost

Classification		Design route	Alternative 1	Alternative 2
Total length		L=16,500	L=15,700	L=15,631
Earthwork volume	Bank filling volume	2,089,142.06	936,152.76	2,529,131.63
	Ground cutting volume	2,562,356.40	5,754,454.51	4,359,833.05
Bridge	0m~100m	6 units / 346m	2 units / 86m	-
	100m~200m	4 units / 540m	1 units / 180m	-
	200m~500m	1 unit / 210m	-	1 units / 260m

	500m 이상		-	1 unit / 600m	2 units / 1,520m
	Sum		11 units / 1,096m	4 units / 866m	3 units / 1,780m
Tunnel	100m~500m		4 units / 920m	12 units / 2,226m	5 units / 860m
	500m~1,000m		2 units / 1,520m	2 units / 1,260m	1 unit / 640m
	1,000m~5,000m		2 units / 2,521m	1 unit / 1,380m	1 unit/ 1,740m
	Sum		8 units / 4,961m	15 units / 4,866m	7 units / 3,240m
Construction cost (Unit: KRW)	Earth-work	Construction cost	6,840,794,612	10,232,715,888	10,238,694,032
		Calculation basis	(Bank filling volume×Unit price)+(Ground cutting volume×Unit price)= (2,089,142.06×1,366)+(2,562,356.40×1,556)	(Bank filling volume×Unit price)+(Ground cutting volume×Unit price)= (936,152.76×1,366)+(5,754,454.51×1,556)	((Bank filling volume×Unit price)+(Ground cutting volume×Unit price)= (2,529,131.63×1,366)+(4,359,833.05×1,556)
	Bridge	Construction cost	48,662,400,000	38,450,400,000	79,032,000,000
		Calculation basis	Bridge length(m)×Unit price =1,096×44,400,000	Bridge length(m)×Unit price =866×44,400,000	Bridge length(m)×Unit price =1,780×44,400,000
	Tunnel	Construction cost	130,474,300,000	127,975,800,000	85,212,000,000
		Calculation basis	Tunnel length(m)×Unit price(4 lanes) = 4,961×26,300,000	Tunnel length(m)×Unit price(4 lanes) = 4,866×26,300,000	Tunnel length(m)×Unit price(4 lanes) = 3,240×26,300,000
	Sum		185,977,494,612	176,658,915,888	174,482,694,032

Note)1. Estimated construction cost is calculated by entering the horizontal alignment and the vertical alignment of the design routes.
2. Not considering the alignment separation of the design routes.
3. Simply applies the unit price per unit volume, without considering the types of structures (Tunnels/Bridges).
4. Calculate the earthwork volume for each design route, candidate route 1, candidate route 2, without considering the dark line data about dark lines (Calculated totally based on earth and soil)

Comprehensive evaluation results of each alternative

Based on the comprehensive evaluation implemented after the individual evaluations for safety, road alignment, environment, and economic feasibility, it is understand that the alternative 2 shows higher priority compared with the alternative 1 and the design route. The result not only means that the alternative 2 proposed by this study acquires more points than the actual design route, subsequently expected to provide a great help in decision making process for actual application, but also means that the method is validated in terms of the feasibility.

Table 16 Comprehensive comparison of the total score

Classification	Score for each alternative			Remarks
	1st priority (3 points)	2nd priority (2 points)	3rd priority (1 point)	
Economic evaluation (Construction cost)	alternative 2 (174.5 billion KRW)	alternative 1 (176.7 billion KRW)	Design route (186 billion KRW)	
Environment evaluation	alternative 2 (17,439)	alternative 1 (18,478)	Design route (31,655)	Resistance value
Road alignment evaluation	alternative 2 (66.42)	alternative 1 (58.76)	Design route (57.09)	
Safety evaluation	Design route (81.3)	alternative 2 (78.9)	alternative 1 (77.3)	

Table 17 Final evaluation for prioritization among the alternatives

Classification	Weight	Points for each alternative		
		Design route	alternative 1	alternative 2
Economic evaluation	1.0	1	2	3
Environment	1.0	1	2	3

evaluation				
Road alignment evaluation	1.0	1	2	3
Safety evaluation	1.0	3	1	2
Sum	-	6	7	**11**
Final priority	-	**3**	**2**	**1**

6. CONCLUSIONS

This study proposes methods and application for selecting the optimal road route by comprehensively taking into consideration the multi evaluation factors such as geometry, environment, traffic safety, and economic feasibility. For this, identical weights are applied respectively for each factor such as geometry, economic feasibility, traffic safety, environment, and consequently the optimal evaluation factors are selected. In order to apply the quantitative evaluation factors, the optimal road design program [2] modified in this study, applies the weights for evaluation factors, such as safety, environment feasibility, geometry, to the 14.8km section of total length of 90km of 00-00 expressway whose basic design was completed recently, and subsequently produces the optimal road route for the expressway. The feasibility of the routes generated through comparison among the actual design routes whose basic design was already completed is validated.

- In order to reflect the safety factor into road design, the study analyzed the relationship between the traffic accidents that occurred along the total length of 2,851km for the recent 3 years and the related geometry. It is analyzed that totally 4 factors, such as length of straight section, length of curve section, curve radius, and vertical slope, are highly applicable for the safety evaluation. Also by developing the evaluation indices, based on the data of actual accidents, for each factor deduced, the study proposes methods for integrating the analysis results into the road design evaluation.
- Based on the results acquired from comparing, alternative 2 ranks first in the evaluation in terms of economic feasibility, environment, and road alignment, while the design route ranks first in the safety evaluation. The result proves that the integrated model proposes by this study for selecting the optimal road route is validated.

It is meaningful that it comprehensively takes into consideration the conflicting multi evaluation factors and subsequently proposes new methods which can be adopted for selecting the optimal road route. The study is expected not only to propose a new direction for selecting the optimal road route in the process of road planning in the future, but also to contribute to the development of user-friendly road design technology in responding to a change in the requirements for roads as the social environment changes.

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